Experiments on combustion of injected fuel in a constant volume chamber

P. CAI, T. KANEKO*, T. YOSHIHASHI, T. OBARA and S. OHYAGI

Department of Mechanical Engineering, Faculty of Engineering, Saitama University,
*Graduate School of Mechanical Engineering, Saitama University,
255 Shimo-Ohkubo, Urawa, Saitama 338-8570 Japan
E-Mail;*caipin@mech.saitama-u.ac.jp*

Abstract

This paper presents the combustion characteristics of methane under direct-injection spark-ignition conditions. A constant volume combustion chamber is used for the experiments. Pressure variations in the combustion chamber were measured by a pressure transducer and the behaviors of the flame were visualized by instantaneous schlieren and direct photography. Effects of igniter position and ignition timing on burning time, on pressure history and on flame propagation are discussed. The results show that the burning time can be reduced considerably together with an increase of the maximum pressure by using earlier ignition timing. The lean flammability limit can be extended by changing igniter position from top to side. Various information can be obtained from the photographs such as a structure of the flame front affected by ignition timing and igniter position, and it is suggested that a suitable ignition timing and igniter position is very important for the lean burning.

Introduction

In recent design of internal combustion engines, fuel-lean burning becomes important. By using this method, the engines can not only achieve higher thermal efficiency which leads to reduce fuel consumption, in other words to reduce CO_2, but also can reduce NOx emission for a lower flame temperature. However, it certainly causes some unavoidable problems, such as difficulty in ignition and increase in burning time. To solve these problems, “direct-injection combustion” is regarded as an effective method, because the ignition property can be improved by providing a locally rich mixture in the vicinity of the spark plug at ignition and the burning time can be shorten by utilizing turbulence induced by fuel jet. Although the direct-injection spark-ignition engine has been developed for a practical use recently, combustion process in engine cylinder is not fully understood yet [1-2].

In the present work, an experimental study on the direct-injection spark-ignition combustion was carried out in a constant volume combustion chamber and effects of igniter position and ignition timing on combustion characteristics (burning time, pressure history) were investigated.

Experimental

Experiments were conducted in a constant volume chamber. Figure 1 shows a schematic of the combustion chamber. A cylindrical chamber has a 100mm diameter, a 50mm length and a volume of 393 cm^3. The chamber contains a pair of parallel optical glass windows on each end to permit optical access throughout the entire chamber. After introducing air into the evacuated chamber through the intake valve, methane was injected into air, and was ignited by one of the three spark plugs at a certain time t_{ig}. In this paper, the time t_{ig} which is a time elapsed from end of injection is called as ignition timing and varied as a parameter. The pressure development in the combustion chamber was measured by a strain gauge type pressure transducer. Instantaneous schlieren photographs were taken by using a Xenon flush lamp with 4 μs duration. Timing of firing the flush lamp was controlled

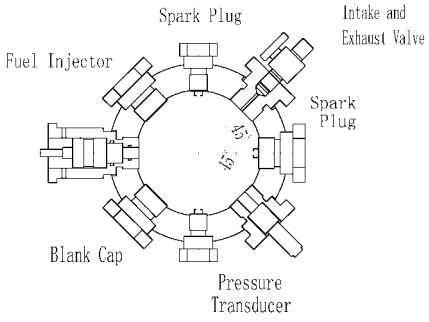


Figure 1 Schematic diagram of the constant volume combustion chamber

by a signal output of the delay circuit. In addition, color pictures of flame were also taken by using a still camera with a shutter speed of 1/8000s to promote a better understanding on combustion process.The experimental conditions are summarized in Table 1.

Table 1 Experimental conditions

Fuel and Oxidizer	CH_4+Air(O_2+3.76N_2)
Overall Equivalence Ratio	0.55,0.6,0.7,0.8,0.9, 1.0,1.1,1.2,1.3
Ignition Time	-43 to 500ms,3min
Injection Gas	CH_4
Injection Pressure	1.6MPa
Injector Location to Spark Plug	Top(90°), Side(180°)
Initial Pressure	101.3±0.5kPa

Results and discussions

Pressure variations in the combustion chamber were measured for each condition. Figure 2 shows pressure variations in the combustion chamber for the condition ϕ=1.0, using an ignition plug at the top (90° from the injector). When a spark was generated after the end of injection, a rapid pressure rise, i.e., a larger pressure increasing rate was observed for an earlier ignition timing, which resulted in a decrease of the main burning time (a time from ignition to peak pressure). Because the mean flow velocity and their turbulence will decay rapidly with time after injection, a decrease in the main burning time should be attributed to the effects of gas flow and their turbulence on enhancement of flame propagation. The maximum pressure was also increased with a decrease in ignition timing. In the case of ignition occurred during injection (t_{ig}= -10 ms), although there was a difference in pressure history, the main burning time and the maximum pressure were almost same with the condition of t_{ig}= 5 ms.

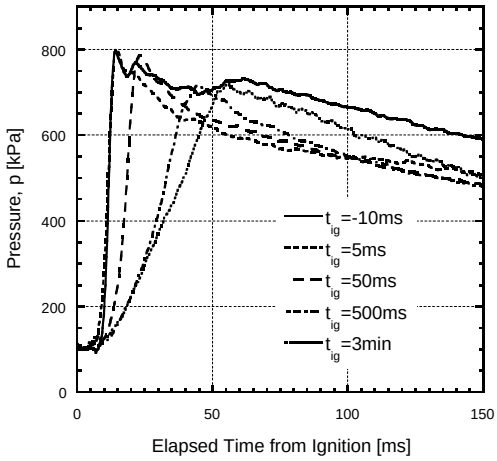


Figure 2 Effect of ignition timing on Chamber pressure histories

Effects of ignition timing and igniter position on the main burning time for various overall equivalence ratios are summarized in Figure3. It shows that using an earlier ignition timing can not only reduce the main burning time but also can diminish a dependence of the main burning time on the overall equivalence ratio. Furthermore, It should be noted that by using an ignition plug on the side (180° from the injector) and a suitable ignition timing, the lean flammability limit can be extended to an overall equivalence ratio of 0.5. These facts imply ignition timing and igniter position are very important for the lean burning. Figure 4 shows the maximum pressure in the chamber. The maximum pressure which is dominated by the heat loss is increased as the ignition time is decreased. Although the heat transfer coefficient should be large if the mean flow velocity is high at shorter ignition time condition, however, the burning time is also shortened a lot, so we can expect that the total heat loss become small when an earlier ignition timing was used.

Fig. 5 (a), (b) show typical schlieren photographs for the condition ϕ=1.0, t_{ig}=5 ms, using the top (90°) and the side (180°) plug, respectively. The effect of turbulence was visible in the whole burning process and the flame surface was finely disturbed. The effect of igniter position on flame propagation appeared at an earlier stage. For a condition of Fig.5(a), a blue flame with irregular shape was observed from direct photographs

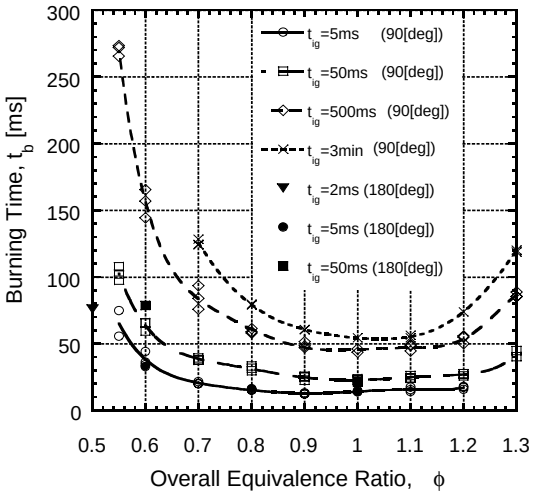


Figure 3 Variation of burning time with overall equivalence ratio

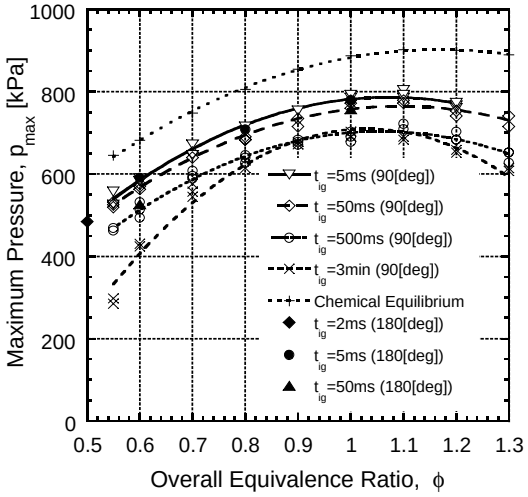
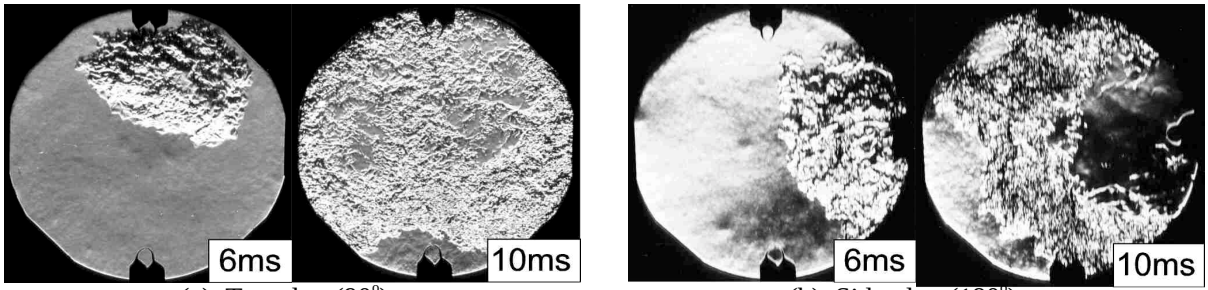


Figure 4 Variation of maximum pressure with overall equivalence ratio



(a) Top plug (90°) (b) Side plug (180°)

Figure 5 Schlieren photographs (ϕ = 1.0, t_{ig} = 5 ms)

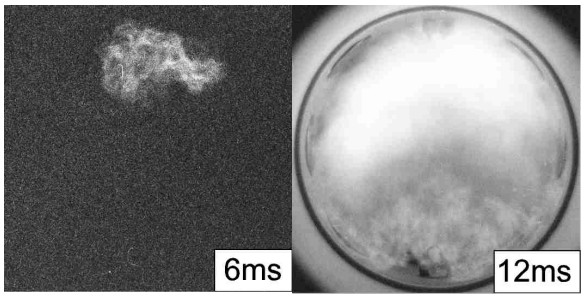


Figure 6 Direct photographs
(ϕ = 1.0, t_{ig} = 5 ms)

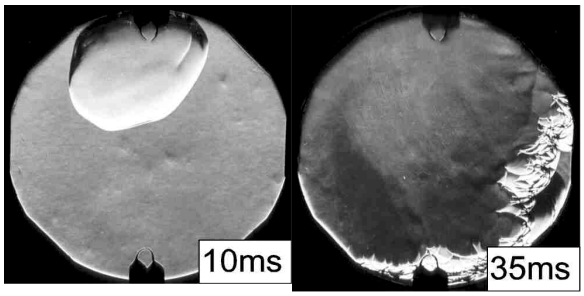


Figure 7 Schlieren photographs
(ϕ = 1.0, t_{ig} = 500 ms)

shown in Fig.6. From Fig.6, it is found that the region near the ignition plug became illuminating as the flame front propagated, which was caused by temperature increase during the process. From color of the flame, it is likely that methane was well mixed with air even at 5 ms after injection. Figure 7 also shows schlieren photographs for the condition ϕ=1.0 but a lager ignition timing t_{ig}=500 ms was used. In this case, the flame front was quite smooth at 10 ms after ignition due to decaying of flow velocity. It was found from experiment that only after the flame covered almost half of the chamber, the flame surface became wrinkled gradually and then large-scale cellular structure was formed on the flame surface.

Concluding remarks

An experimental study on the direct-injection spark-ignition combustion was carried out in a constant volume combustion chamber. Effects of igniter position and ignition timing on burning time, on pressure history and on flame propagation were investigated. From the experimental results the following conclusions can be drawn:

(1) The burning time can be reduced considerably together with an increase of the maximum pressure by using earlier ignition timing.
(2) The lean flammability limit can be extended by changing igniter position from top to side.
(3) Various information can be obtained from the photographs such as a structure of the flame front affected by ignition timing and igniter position, and it is suggested that a suitable ignition timing and igniter position is very important for the lean burning.

References

[1] Ohsuga, M., Shiraishi, T., Nogi, T., Nakayama, Y., Sukegawa, Y., 1997, “Mixture Preparation for Direct-Injection SI Engines” *SAE Paper* 970542, pp.794-801.

[2] Kagawa, R., Okazaki, S., Somyo, N., Akagi, Y., 1993, “A Study of a Direct-Injection Stratified–Charge Rotary Engine for Motor Vehicle Application” *SAE Paper* 930677, pp.918-926.